Citation for published version:
Rivadulla, AR, Gore, S, Preatoni, E & Richter, C 2020, 'Athletic groin pain patients and healthy athletes demonstrate consistency in their movement strategy selection when performing multiple repetitions of a change of direction test', *Journal of Science and Medicine in Sport*, vol. 23, no. 5, pp. 442-447.
https://doi.org/10.1016/j.jsams.2019.12.011

DOI:
10.1016/j.jsams.2019.12.011

Publication date:
2020

Document Version
Peer reviewed version

Link to publication

Athletic groin pain patients and healthy athletes demonstrate consistency in their movement strategy selection when performing multiple repetitions of a change of direction test

Abstract

Objectives: To report the consistency in movement strategy selection in athletic groin pain patients and to assess whether there are differences in consistency between athletic groin pain patients and healthy athletes.

Design: Cross sectional exploratory study.

Method: Twenty athletic groin pain patients and 21 healthy athletes performed 15 repetitions of 110º change of direction task. Lower limb and trunk kinematics alongside ground reaction forces were collected. A correlation-to-mean algorithm was used to allocate each trial to a movement strategy using kinematic and kinetic features. Mann-Whitney U tests were used to compare the frequency of the most selected strategy (i.e. consistency) and fuzziness between athletic groin pain patients and healthy athletes. Chi-squared tests were used to compare the strategy selection between athletic groin pain patients and healthy athletes.

Results: There were no differences between groups in consistency in movement strategy selection (>80%). Athletic groin pain patients tended to select a knee dominant movement strategy whereas healthy athletes preferred an ankle dominant movement strategy.

Conclusions: The consistency observed in athletic groin pain patients supports the implementation of movement strategy assessments to inform AGP rehabilitation programmes tailored to athletes' deficiencies. Such assessments could help enhance the success of

athletic groin pain rehabilitation. Differences in movement strategy selection might not be associated with injury state since there were no differences between athletic groin pain patients and healthy athletes.

Key words: kinematics; kinetics; cutting; rehabilitation; movement classification

Practical implications

- Athletic groin pain (AGP) patients demonstrate consistency in their movement strategy selection over multiple repetitions of a change of direction test.
- Consistency in movement strategy selection does not seem to be affected by AGP and is similar to the levels shown by healthy controls.
- Movement strategy classification through a simple correlation-to-mean approach shows the potential to assist clinicians in the design of more individualised AGP rehabilitation interventions.
- Caution is advised in recognising the level of detail that classification approaches could provide in relation to AGP injury aetiology and the role of single elements (e.g. individual joints).

Introduction

The aetiology of overuse injuries is challenging for researchers due to the lack of a single identifiable event that triggers the pathological condition. Whereas acute injuries result from a traumatic accident that leads to severe tissue damage[1], overuse injuries such as athletic groin pain (AGP) are thought to be the consequence of an accumulation of micro-traumas and have an insidious onset[2–4]. AGP is typically observed in field sports male athletes[5,6] who are required to accelerate/decelerate and perform changes of direction repeatedly[7] and presents as an irritation of the groin/hip area tissues. There are multiple factors associated with overuse injury[8,9] and some of them are inevitably related to the movement patterns exhibited by an athlete[10]. Hence, it is crucial to understand what biomechanical factors relate to overuse injuries to inform better practices for their prevention and rehabilitation.

Typical approaches to determine the mechanisms of overuse injuries within biomechanics have assumed that individuals sharing the same condition also share the same injury mechanism and thus, have used a single group analysis[11]. However, this method may overlook the existence of various movement patterns within an apparently homogeneous cohort[12,13]. An alternative approach is the use of statistical clustering to identify features (e.g. kinematic and kinetic variables) that best describe homogeneous clusters (e.g. movement strategies) within a specific population[14]. In the study of overuse injuries, Franklyn-Miller et al.[7] investigated the presence of movement clusters in AGP patients performing a maximum effort 110º change of direction using hierarchical clustering and identified three distinct movement strategies. The three movement strategies were labelled as hip, knee or ankle dominant, based upon the work performed by each of the lower limb joints. These strategies were not related to the anatomical structure affected and could represent different mechanisms of distributing the load between segments that could lead to AGP or may be compensatory movements due to injury.

The existence of different movement strategies in AGP athletes independent of their symptomatic structure questions the effectiveness of tissue-focused AGP rehabilitation[7]. Indeed, the high rate of AGP recurrence[15,16] highlights the room for improvement in rehabilitation practice. Assessing an athlete's movement strategy enables the identification of individual deficiencies that could then be used to target the specific needs of an athlete in AGP interventions, potentially increasing rehabilitation success. Further work[17] towards the implementation of movement strategy assessments in AGP rehabilitation has presented an algorithm that uses five kinematic and kinetic features (Table 1) to assign athletes to the three movement strategies previously proposed[7]. This method also exploits the definition of *fuzziness* as the strength of a membership to the assigned movement strategy. However, two questions that could dispute the validity of interventions specific to an athlete's movement strategy have not been examined yet:

The movement strategies identified by Franklyn-Miller et al. (2016)[7] were found only considering one change of direction manoeuvre per individual, and therefore it is unknown whether AGP athletes use the same strategy over repetitions of the same movement. The repetitive loading nature of overuse injuries[10] makes it critical to understand whether an AGP athlete uses the same movement strategy over multiple cycles of a task prior to designing interventions specific to a single strategy. Secondly, how these movement strategies relate to the mechanisms of AGP injury is not fully understood. It has been speculated that AGP could originate due to an inability to execute different strategies (i.e. consequently overloading the same tissues) or due to the performance of the extreme characteristics of a movement pattern[7]. Previous work studying joints in isolation has found reduced variability in AGP athletes compared to healthy athletes performing changes of direction[16], which seems to align with the former hypothesis. Comparison between AGP and healthy athletes could help us understand if a lack of consistency in movement strategy selection or an inability to perform multiple strategies are associated with injury state in dealing with repetitive load. Further, the study of fuzziness could also elucidate if the proposed movement strategies used by AGP athletes are "extreme" movement patterns[7] compared to those used by healthy athletes.

The purpose of this study was to investigate whether: a) AGP athletes consistently select the same movement strategy over multiple repetitions of a change of direction task; b) AGP and healthy athletes exhibit different consistency in their movement strategy selection; and, c) there are any differences in fuzziness between AGP and healthy athletes. We hypothesised that AGP and healthy athletes will exhibit differences in their consistency in movement strategy selection, and that healthy athletes will be fuzzier than AGP athletes. The outcome of this research could support the implementation of movement strategy assessments in AGP rehabilitation whilst also providing a better understanding of the proposed movement strategies[7] and their relation to AGP injury.

Methods

Twenty male athletes presenting with AGP (age: 24.8±4.9 years, height: 1.81±0.05 m, mass: 81.0±6.7 kg, ongoing symptoms for 94±57 weeks) and 21 healthy male athletes (age: 25.0±4.9 years, height: 1.80±0.06 m, mass: 80.9±11.0 kg) participated in this exploratory cross-sectional study. Inclusion criteria for both groups included being a field sports player aged 18-35 at the time of testing. Athletes in the AGP group were tested prior to starting their rehabilitation after being diagnosed at the Sports Surgery Clinic (Dublin, Ireland) as per standardised protocol. Clinical diagnosis was made by two consultant sports physicians and a senior physiotherapist based on injury history review, clinical examination, MRI and the Copenhagen hip and groin outcome scores (HAGOS)[25]. A detailed description of the diagnosis protocol can be found in Falvey et al.[18]. Healthy athletes had no history of hip/groin pain and no chronic or acute lower-limb injury in the 12 months prior to testing. Written informed consent was obtained from participants before testing and ethical approval was granted by the Sports Surgery Clinic Hospital Ethics Committee (REF SSC0024).

Athletes completed a standardised warm-up including a 3-minute jog at self-selected pace, 5 body weight squats and 2 submaximal practice trials of a planned 110º change of direction[7]. The testing protocol included 15 repetitions of a maximum effort planned 110º change of direction (Figure 1A). This manoeuvre is commonly used in AGP clinical biomechanical evaluation[7,24] and is favoured over rectangle and acute angles due to its greater requirements to decelerate, rotate and re-accelerate for the athlete. AGP athletes performed the task with their injured side (if both, most symptomatic was selected) whilst healthy athletes used their dominant leg. Dominant leg was defined as the one used to kick a ball as far as possible[19]. Instructions were kept consistent across participants and within each testing session. The 15 trials were completed in sets of 3, with 30 seconds rest between trials and 2 minutes between sets. Trials were excluded if the athlete failed to complete full contact with the force platforms when changing direction. However, references to the force platforms in the instructions were avoided to prevent participants from aiming at them, potentially modifying their technique.

A 10-camera motion capture system (Vicon Motion Systems, Oxford, UK) and two force platforms (BP400600, AMTI, USA) synchronised through Nexus software (Nexus 1.8.5, Vicon Motion Systems, Oxford, UK) were used to record three-dimensional marker trajectories at 200 Hz and ground reaction forces (GRFs) at 1000 Hz. Twenty-eight reflective markers (d = 14 mm) were placed on anatomical landmarks (figure 1B) as per the Plug-in-Gait model (Vicon Motion Systems, Oxford, UK). Marker trajectories and GRFs were filtered using a Butterworth low-pass filter (4th order, zero lag, bidirectional) with a cut-off frequency of 15 Hz[20]. Marker trajectories were used to estimate body segments' position and orientation in three dimensions and then joint angles were calculated. Inverse dynamics was used to calculate tri-planar joint moments that were normalised to athletes' body mass. GRFs were explored to identify the start (frame prior to GRF>25 N) and end (frame after GRF<25 N) of contact with the platforms (i.e. stance phase). Joint kinematics and kinetics time series were normalised to 101 data points and landmark registered to the start of the concentric phase (i.e. first frame in which the centre of mass vertical velocity > 0 m/s) using dynamic time warping[21,22]. This process aligned every trial's start of the concentric phase at 47% of the waveform.

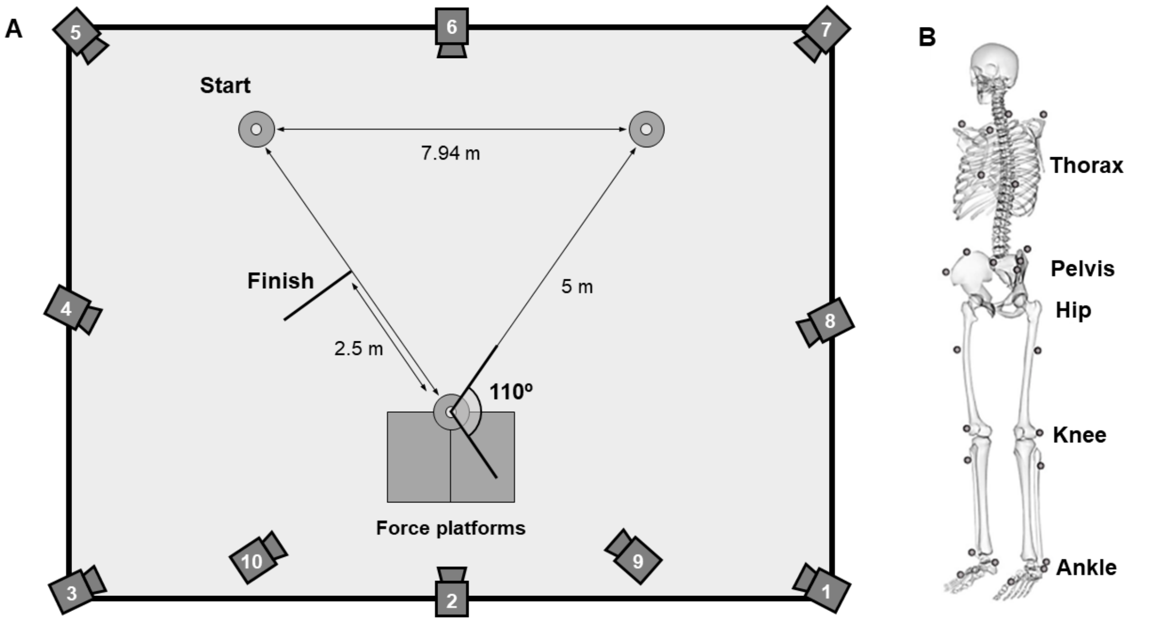

Figure 1. Laboratory set up for a cut with the left leg (A): Athlete starts from the cone on the top left corner (Start), runs maximally towards the one on the top right corner, changes direction by performing a single contact with the left foot outside the cone, runs maximally towards the bottom cone, changes direction again by completing a single contact with the left foot outside the cone (i.e. on the force platforms) and runs maximally towards the Finish line. Marker set used (B).

A correlation-to-mean algorithm[17] was used to classify athletes' movement patterns exhibited in each trial. Kinematic and kinetic variables over a defined phase of the waveform (Table 1) were extracted and used as input for the classification model. For each trial, the mean of each feature was calculated and stored in a *feature vector* (nx1, where n=5 is the number of features). The *overall reference vector* (i.e. vector containing the overall mean of the entire population for each feature) and each *movement strategy centroid* (i.e. vector containing the mean of each feature for each movement strategy) were extracted from previous work[17] (Table 1).

Table 1. Features, overall reference vector, movement strategy centroids (MS)[17], and descriptive statistics of each movement strategy for the AGP and healthy groups.

Features[a]	Overall	MS 1	MS 2	MS 3
Hip flexion (27-41)[b]	51.3	52.2	60.7	41.3
Ankle rotation (45-56)	-21.5	-34.4	-17.2	-19.4
Ankle dorsiflexor moment (39-48)	23	25.6	20.2	24.6
Thorax lateral sway (97-101)	13.8	12.3	9.1	19.3
Hip abduction (1-7)	-19	-18.9	-18.4	-19.7
Descriptive statistics (mean ± standard deviation) for the AGP group				
Hip flexion (27-41)		54.4±7.3	63±5.2	39.3±8
Ankle rotation (45-56)		-37±9.3	-23.9±6.9	-24.9±6.6
Ankle dorsiflexor moment (39-48)		25.8±6.3	19±5.1	26.9±8.9
Thorax lateral sway (97-101)		15±8	3.5±9.6	22.7±8
Hip abduction (1-7)		-16.5±6.6	-16.5±6	-19.9±6.6
Descriptive statistics (mean ± standard deviation) for the healthy group				
Hip flexion (27-41)		48±6.3	58.7±9.8	30.5±17.9
Ankle rotation (45-56)		-35.8±5.2	-25.9±4.7	-25.3±11.9
Ankle dorsiflexor moment (39-48)		23.9±5.9	15.3±9.2	27.2±8.2
Thorax lateral sway (97-101)		14.5±8.1	2.9±10.8	26.4±10.1
Hip abduction (1-7)		-18.4±6.4	-18.2±3.8	-20.0±19.6

[a] Angles are expressed in degrees and moments are expressed in N·m/kg.
[b] Ranges between brackets represent the phase of the waveform defining the feature.

For each trial, the overall reference vector was subtracted from the trial's feature vector and from each movement strategy centroid. These vectors were then correlated (Equation 1).

$$r_i = corr[(FeatVec - OverallRef), (MSCentroid_i - OverallRef)] \quad (1)$$

Where *r* is the Pearson's correlation coefficient, *i* is the number of movement strategies, *FeatVec* is the feature vector of the trial, *OverallRef* is the overall reference vector and *MSCentroid* is the movement strategy centroid.

The membership of an observation was determined using the computed r values – highest correlation indicates the most likely membership. To assess the strength of the membership of each trial to a movement strategy, a *fuzziness ratio* was calculated using Equation 2[17]. This allows for the distinction between cases holding characteristics of solely one group (i.e. *logic*, closer to one movement strategy centroid) and cases holding characteristics of two groups (i.e. *fuzzy*, somewhere in between two movement strategies).

$$fuzziness\ ratio = \frac{r_2 + 1}{r_1 + 1} \qquad (2)$$

Where r_2 is second highest correlation coefficient (i.e. less likely membership) and r_1 is correlation to the selected movement strategy (i.e. most likely membership).

For each participant, the most frequently selected movement strategy was identified, and consistency was defined as the number of trials in which that strategy was selected. A Mann-Whitney U test was used to compare consistency in movement strategy selection between AGP and healthy athletes. Chi-squared tests were used to compare the frequency of selection of each strategy between AGP and healthy athletes. The average fuzziness ratio of each participant was also calculated, and Mann-Whitney U test was used to compare both groups. Statistical significance was set at α=0.05. Time and landmark registration, feature extraction, classification and statistical analysis were performed in Matlab (2018a, Mathworks, USA).

Results

The AGP group included athletes with diagnosed injuries to the aponeurosis (55%), hip adductor (15%), hip flexor (15%), hip joint (10%) or hip flexor and hip joint (5%). Mean HAGOS scores were: symptoms 62.25±17.35; pain 73±15.17; activities of daily living 75±17.70; sports and recreation 55.31±18.37; participation in physical activity 31.25±31.55; and quality of life 37.75±14.64. Three trials from one of the AGP athletes were excluded due to partial contact with the force platforms. Descriptive data of the features used for classification are included in Table 1. AGP and healthy athletes did not show differences in their consistency in movement strategy selection (AGP, 80.3±16.7%; healthy, 83.5±15.6%, p=0.543). However, AGP and healthy athletes demonstrated differences (χ^2=20.923, p<0.001) in their preferred movement strategies (Figure 2): Movement strategy 1 (65%) was the most frequently selected strategy in the AGP group followed by movement strategy 3 (20%) and movement strategy 2 (15%). Healthy athletes preferred movement strategy 3 (42.9%) followed by movement strategy 1 (33.3%) and movement strategy 2 (23.8%). No differences in the fuzziness ratio were observed between groups (AGP = 0.65±0.12, healthy = 0.68±0.15, p=0.368).

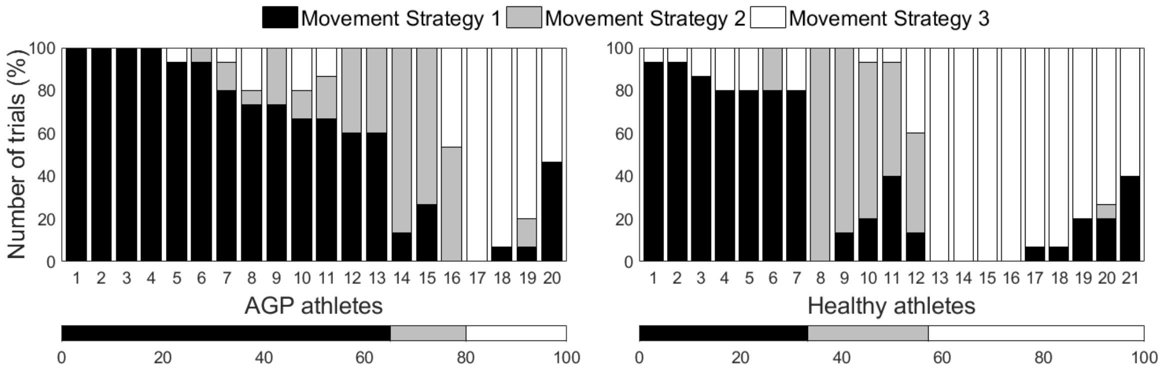

Figure 2. Movement strategy selection in the AGP (top left) and healthy group (top right). Most frequently selected strategy (%) in the AGP (movement strategy 1: 65%, movement strategy 2: 15% and movement strategy 3: 20%; bottom left bar) and healthy group (movement strategy 1: 33.3%, movement strategy 2: 23.8% and movement strategy 3: 42.9%; bottom right bar).

Discussion

This study investigated the characteristics and consistency of the movement strategies adopted by AGP and healthy athletes when performing multiple repetitions of a maximum effort 110º change of direction. Our results demonstrate that AGP athletes tend to choose movement strategies consistently when repeating the same change of direction manoeuvre multiple times, and that they are no less consistent than healthy controls. Such findings indicate that there is scope for the implementation of movement strategy assessments in AGP rehabilitation to drive clinical interventions. Exercise based rehabilitation[23] programmes enhancing the importance of intersegmental coordination[24] have been found to outperform those focusing on isolated muscle strength and reported pain-free return to play rates and HAGOS scores[25] comparable to surgical operations[26]. Movement strategy assessments could further enhance the success of AGP rehabilitation by assisting clinicians to create individualised movement-focused interventions targeting the specific deficiencies of an athlete.

Our first hypothesis was rejected as AGP and healthy athletes showed no differences in their consistency. An individual's movement strategy can be seen as a multi-segmental coordinative pattern product of extensive practice[27] and it appears that the structure of these patterns is not affected by AGP injury to an extent that is detectable by the correlation-to-mean method. However, AGP and healthy athletes demonstrated differences in their movement strategy selection. The most frequently selected movement strategy in the AGP group (movement strategy 1) has been described as knee dominant[7]. Healthy athletes tended to adopt movement strategy 3, which has been defined as ankle dominant. A recent study on biomechanical changes post-rehabilitation in AGP athletes has found that ankle work in a 110º change of direction test was increased after the intervention[24]. These findings combined highlight the importance of ankle's action in changing of direction, which is often disregarded in knee and hip injury research[7]. The ankle is the first major joint in the kinetic chain and has a crucial role with respect to the magnitude of load transmitted to the upper joints. Emphasising the action of this joint in change of direction manoeuvres could be a valuable addition to AGP prevention and rehabilitation programmes. Movement strategy 2, which has been previously labelled as hip dominant due to increased hip work, was the least selected in both groups in agreement with previous work on AGP athletes[7].

The classification was complemented with the analysis of fuzziness to provide a more comprehensive look at the continuum of movement patterns existing between two movement strategy centroids. There were no differences between groups in the fuzziness ratio, suggesting the movement patterns used by both groups were at a similar distance to the centroid of the assigned movement strategy. Contrary to our hypothesis, AGP athletes did not appear to be closer to the movement strategy centroids than healthy athletes, and therefore the proposed movement strategies do not seem to be more extreme movement patterns as speculated by Franklyn-Miller et al. (2016)[7]. The similar consistency and fuzziness observed in both groups stresses the importance of considering the multifactorial aetiology of overuse injuries[8,10]. Genetics, anatomy or load management may predispose some individuals to injury whilst others manage to stay healthy despite presenting with similar movement patterns. However, it must be noted that the correlation-to-mean approach used in this study utilises a reduced number of features and provides a holistic view. More detailed analyses are needed to better understand the aetiology of overuse injuries at finer levels (e.g. joint/segment level).

There are some limitations to the present findings. Given the novelty of the data analytics procedure, no formal power analysis could be conducted. Twenty AGP patients were included as the largest sample that could be examined given the constraints of collecting a large number of trials. However, the number of AGP patients within this study compares favourably to previous AGP biomechanics research[16]. Changing of direction in field sports may occur in multiple angles[28] and directions[29] and this study focused on planned 110º manoeuvres. Whilst we acknowledge that results may vary in unplanned situations, the use of the injured side to perform the change of direction in AGP patients was selected to examine the response to stress on the affected area. The protocol included 15 cuts divided in sets with rest in between. The number of cuts and fatigue condition would inevitably be different in an 80-90 minutes match[30]. It is imperative to note that the movement strategies are the product of statistical clustering and their ecological validity and practical impact on AGP rehabilitation is yet to be proved or discarded by future clinical work. Further, the three movement strategies were found in AGP athletes and their ability to represent healthy athletes' movement in this study might not be optimal. However, the similar fuzziness observed in the AGP and healthy groups indicates we could be equally confident in the allocations to the different movement strategies performed by the correlation-to-mean algorithm regardless of injury condition. This suggests that the present movement strategies captured healthy movement patterns adequately. The presence of the proposed movement strategies in healthy athletes needs to be confirmed in further research as it could allow for prospective movement strategy assessments in healthy athletes. Such assessments could provide a better understanding of the development of AGP (e.g. does a change in preferred movement strategy promote AGP or does the development of AGP promote a change in movement strategy?) and inform better prevention practices.

Some methodological considerations could also be addressed in future studies to facilitate the implementation of movement strategy assessments. Collecting the kinematic and kinetic features currently needed for the classification involves using motion capture and force platforms, which may not be easily accessed by clinicians. Simplifying the model could be investigated by replacing the ankle dorsiflexor moment feature for collinear features involving only kinematics. Due to segments' linkage in human body, multicollinearity is frequently seen amongst biomechanical features. Should the accuracy of the model not be reduced by this change, the use of inertial measurement units to collect the desired features could be explored. Such technologies could provide a more accessible means for practitioners to assess athletes' movement strategies, bridging the gap between biomechanics research and clinical application.

Conclusion

Our findings demonstrate that AGP athletes tend to choose movement strategies consistently over multiple repetitions of a change of direction test and provide evidence to support the implementation of movement strategy assessment in AGP clinical interventions. Such assessments could assist clinicians in the development of movement-focused programmes tailored to the specific deficiencies of an individual, potentially enhancing the success of AGP rehabilitation. Further, the similar results observed in healthy athletes indicate that consistency in movement strategy selection may not be affected by AGP. Lastly, the movement strategies used by AGP athletes cannot be described as more extreme than those used by healthy athletes, stressing the importance of considering AGP's multifactorial aetiology.

Acknowledgements

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors. We would like to thank the Biomechanics team at the Sports Surgery Clinic for their invaluable assistance in data collection and data processing for this study.

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